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A PRODUCTION ENGINEERING MEASURE

FOR TWO L BAND SOLID STATE

MICROWAVE FREQUENCY SOURCES

QUARTERLY REPORT NO. 3

COVERING THE PERIOD 30 NOVEMBER 1976 TO 28 FEBRUARY 1977

PREPARED UNDER CONTRACT DAAB07-76-C-0026

MANUFACTURING METHODS AND TECHNOLOGY ENGINEERING PROGRAM

BY

COLLINS RADIO GROUP

HYBRID MICROELECTRONICS DIV.

1200 N. ALMA RD.

RICHARDSON, TX 75080

WRITTEN BY: JEROME K. MCCOY

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ABSTRACT

This report describes the specifications and approach, details the work completed in the design and fabrication of two L Band solid state frequency sources, and describes the progress made towards an eventual high rate production demonstration of these two circuits. These two circuits are a Modulator/Transmitter for Radiosonde applications and an FM Source.

The third set of engineering samples have been completed and performance data is available.

One important advantage of thick film is the ability to screen conductor paste thru a hole in the substrate. The results of the investigation into this process and into other thick film characteristics are presented.

Production planning for the Confirmatory Samples is in progress and plans have been formulated for the delivery of the fourth set of engineering samples.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

REPORT DOCUMENTATION PAGE

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This report describes the specifications and approach, and details the work completed in the design and fabrication of an L Band Radiosonde Modulator/Transmitter and an L Band FM Source. Q of microstrip resonators and the ability to screen conductor material through substrate holes are being investigated in the thick film materials evaluation program. Production planning is in progress and plans have been formulated for the fourth set of engineering samples.

2.1.2 Design Considerations

2.1.2.1 Oscillator Frequency Stability - It had been recognized in the early stages of the Radiosonde development that the frequency stability criterion (4 MHz max. change over the -70°C to +70°C operating temperature range) was the most difficult technical problem to be solved on the modulator/transmitter. The first shipment of engineering samples delivered in August of 1976 was thoroughly tested over temperature with the result that only 3 units met the 4 MHz stability spec, the average being 7 MHz. As reported in the test report submitted with the second set of engineering samples, temperature testing was suspended because of a substrate cracking problem (cracking problem was resolved, see page 2-17). The two units that were tested met the frequency stability requirement. However, the lack of sufficient data prevented a meaningful conclusion.

The effort this past quarter was directed toward determining a solution to this problem. Towards this goal the following investigations were undertaken:

1. Determine the temperature coefficient of capacitance for rutile (TiO_2) dielectric.
2. Determine the effect of temperature on the resonator network.
3. Determine the effect of the bias network on the frequency stability.
4. Determine the frequency sensitivity to supply voltage.

5. Determine the effect of the rutile capacitor value and location on the frequency stability.
6. Determine the effect of output power on the frequency stability.
7. Determine the effect of sealing the oscillator.

Temperature Coefficient of Capacitance (TCC)

A single rutile capacitor was soldered to a copper plate and wired continuously to a Bouton Capacitance Bridge. The copper plate was placed in a oven and run from -50°C to +70°C. Figure 2 is a plot of the data from which the TCC can be determined.

Capacitance @ 10°C = 3.07 Pf

$$TCC = \frac{-(3.2 - 2.95)\ Pf}{120°C} = \frac{-.2083 \times 10^{-2} Pf}{°C} = \frac{-\ .2083/3.07}{°c}\ \%$$

$$\frac{-.0676\%}{°C} = \frac{-676\ PPM}{°C}$$

This result agrees well with numbers of ≈-800PPM/°C reported by RCA.

SCHEMATIC
RADIOSONDE OSCILLATOR

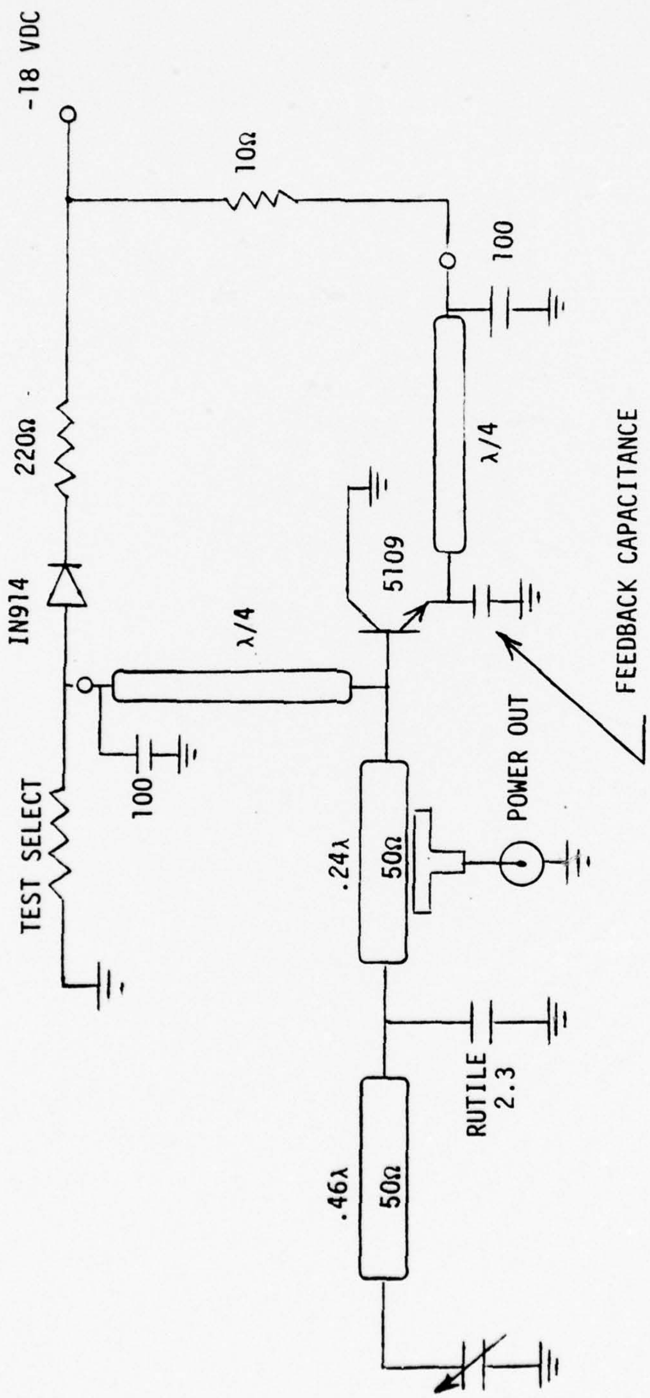


FIGURE 1

RUTILE CAPACITOR
CAPACITANCE CHANGE WITH TEMPERATURE

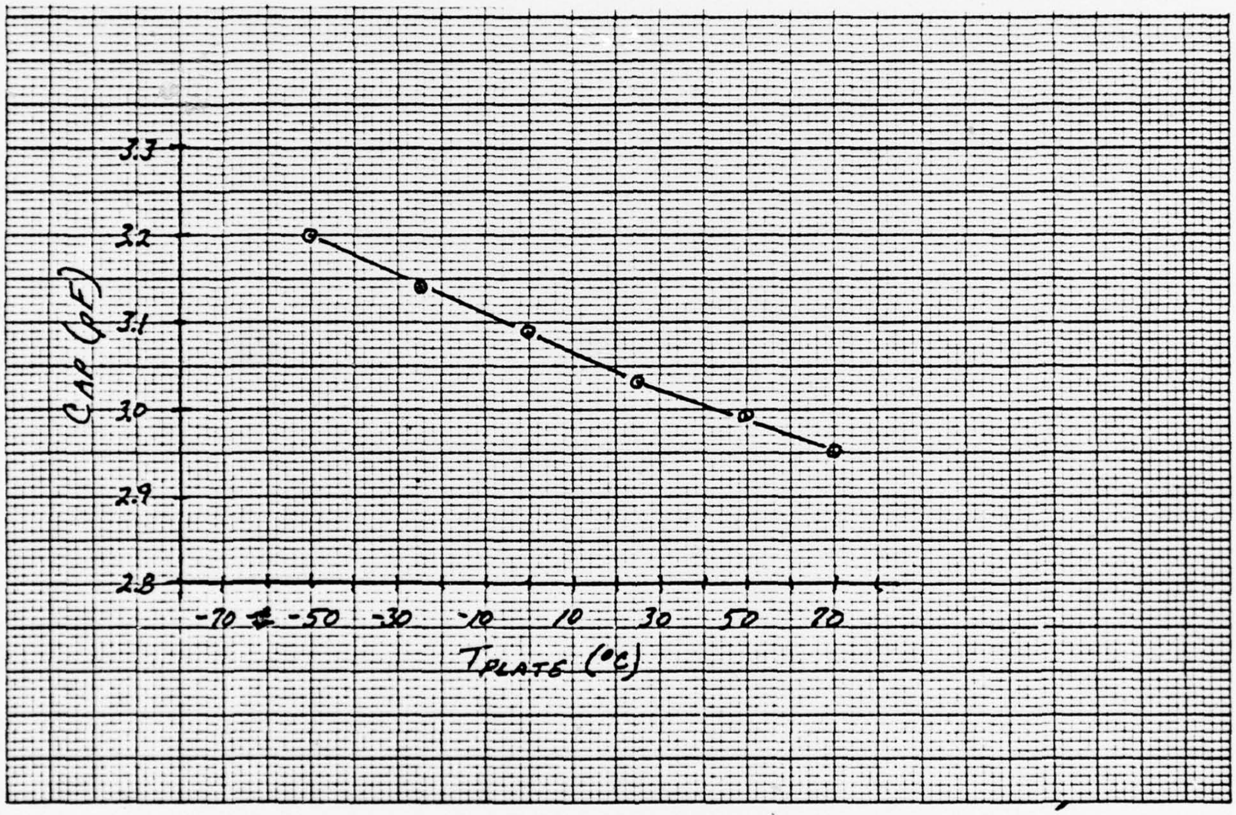


FIGURE 2

Effect of Temperature on the Resonator Network

Referring to Figure 1, the impedance of the base resonator network was measured over the temperature range. This measurement includes the effect of the rutile capacitor and the mechanical variation of the tuning screw. The 50 OHM load remained outside the oven to eliminate its temperature variation. Figure 3 is a graph of the impedance phase with temperature over the operating band. Note that the phase at -70°C and +70°C is approximately the same, showing the effect that the rutile capacitor has in stabilizing the phase for a network that would, without the rutile, have a more linear phase/temperature relationship.

Effect of the Bias Network

The effect that the bias network (refer to Figure 1) has on the frequency stability was investigated to determine if a circuit change there could improve the stability. First the frequency and power stability over temperature was determined with the bias network shown in Figure 1 held outside the oven. Then similar data was taken while the collector current was held constant over temperature by varying an external bias resistor. This data is presented in Figure 4. Note the difference in the frequency stability for the two cases is minimal; the significant effect is on the output power as shown in the lower graph of Figure 4.

PHASE OF
OSCILLATOR RESONATOR NETWORK

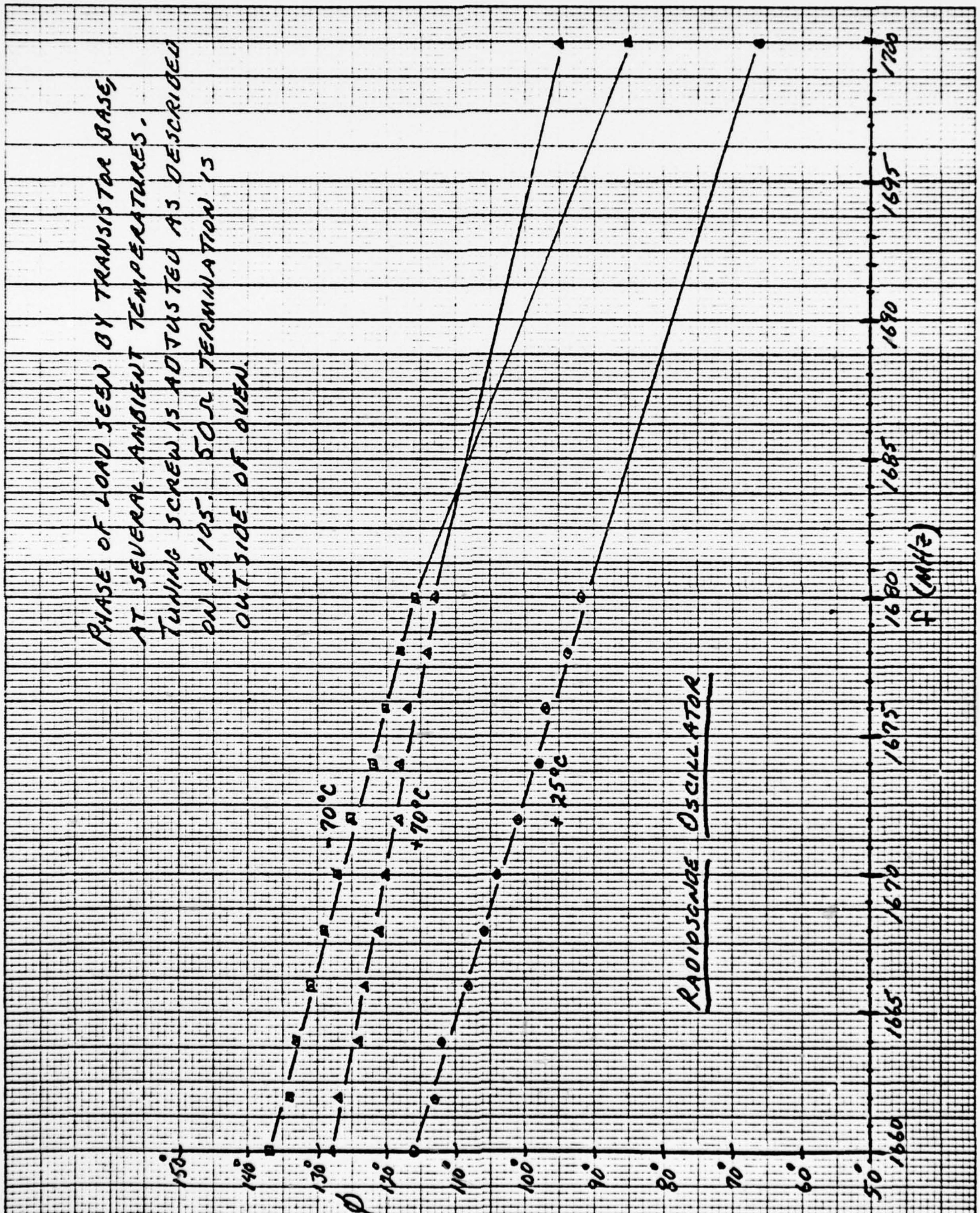


FIGURE 3

RADIOSONDE FREQUENCY STABILITY
EFFECT OF BIAS NETWORK

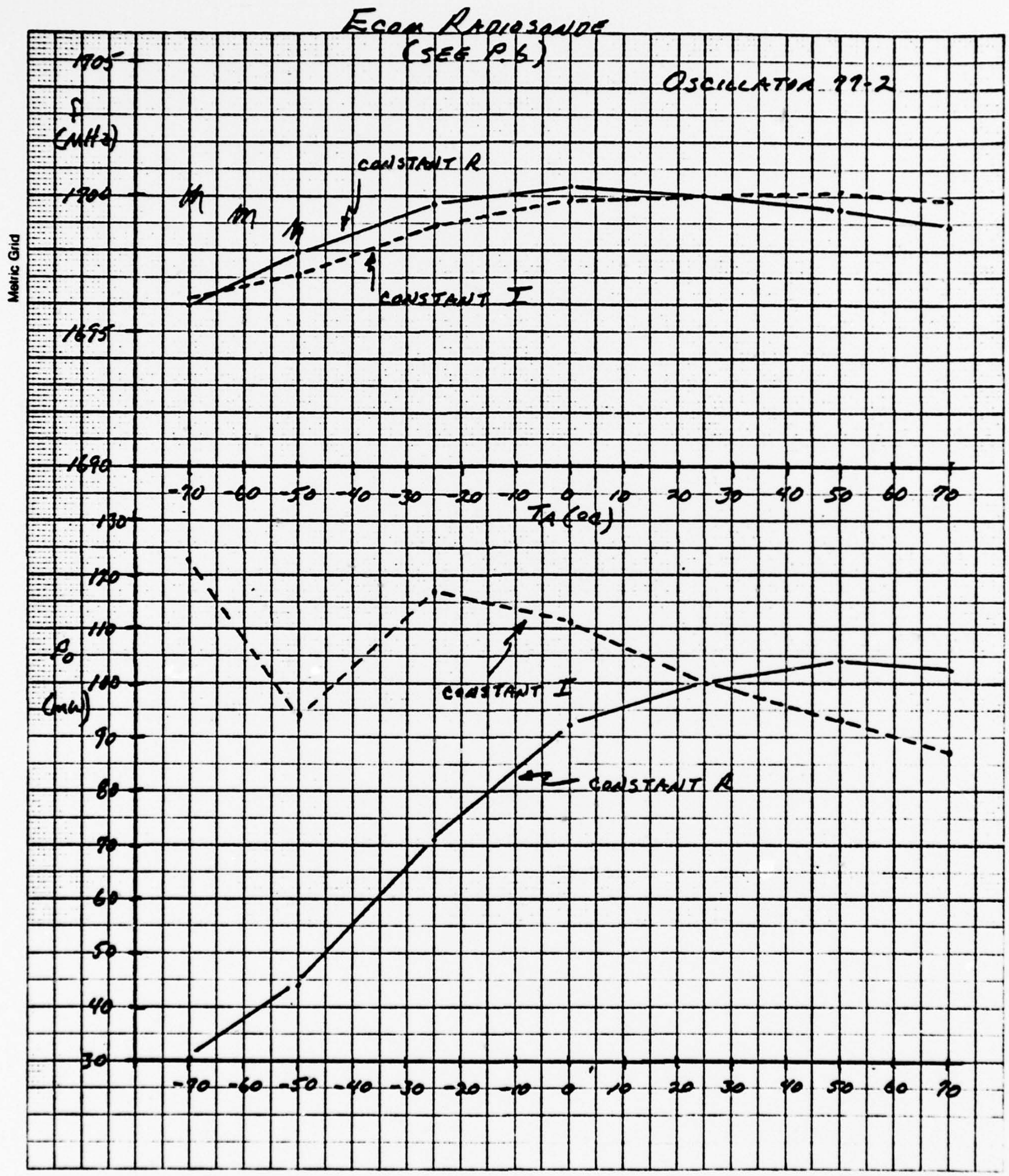


FIGURE 4

Frequency Sensitivity to Supply Voltage

The frequency sensitivity to the supply voltage was determined by testing two units at room temperature using the standard bias network and recording the oscillator frequency versus the supply voltage. This data is plotted in Figure 5. The slope of these curves at 18 volts is approximately .94 MHz/volt. The modulator/transmitter uses a three terminal negative voltage regulator (Motorola No. MC7918CP). This device had previously been characterized over the temperature range and over the input voltage range (-20 to -30DC) and has a maximum variation of 300 m volt. This value corresponds to a frequency variation of .28 MHz which is 7% of the total allowable frequency change.

Effect of Rutile Capacitor Size and Location

The sensitivity of the frequency stability to the rutile capacitor size was determined by simply changing the capacitor value and running temperature data. This data, presented in fig. 6, shows that the stability is not particularly sensitive to the capacitor value in the range of 2.3 to 3.5 Pf.

The effect of the location of the rutile was investigated by moving the capacitor to either side of the nominal position by .065 inch. As illustrated in Figure 7, the position has a dramatic effect on the stability and looks encouraging from the standpoint that a judicious selection of the location could improve the stability above that of position two ($\pm$1.75 MHz).

VARIATION OF OSCILLATOR FREQUENCY
WITH SUPPLY VOLTAGE

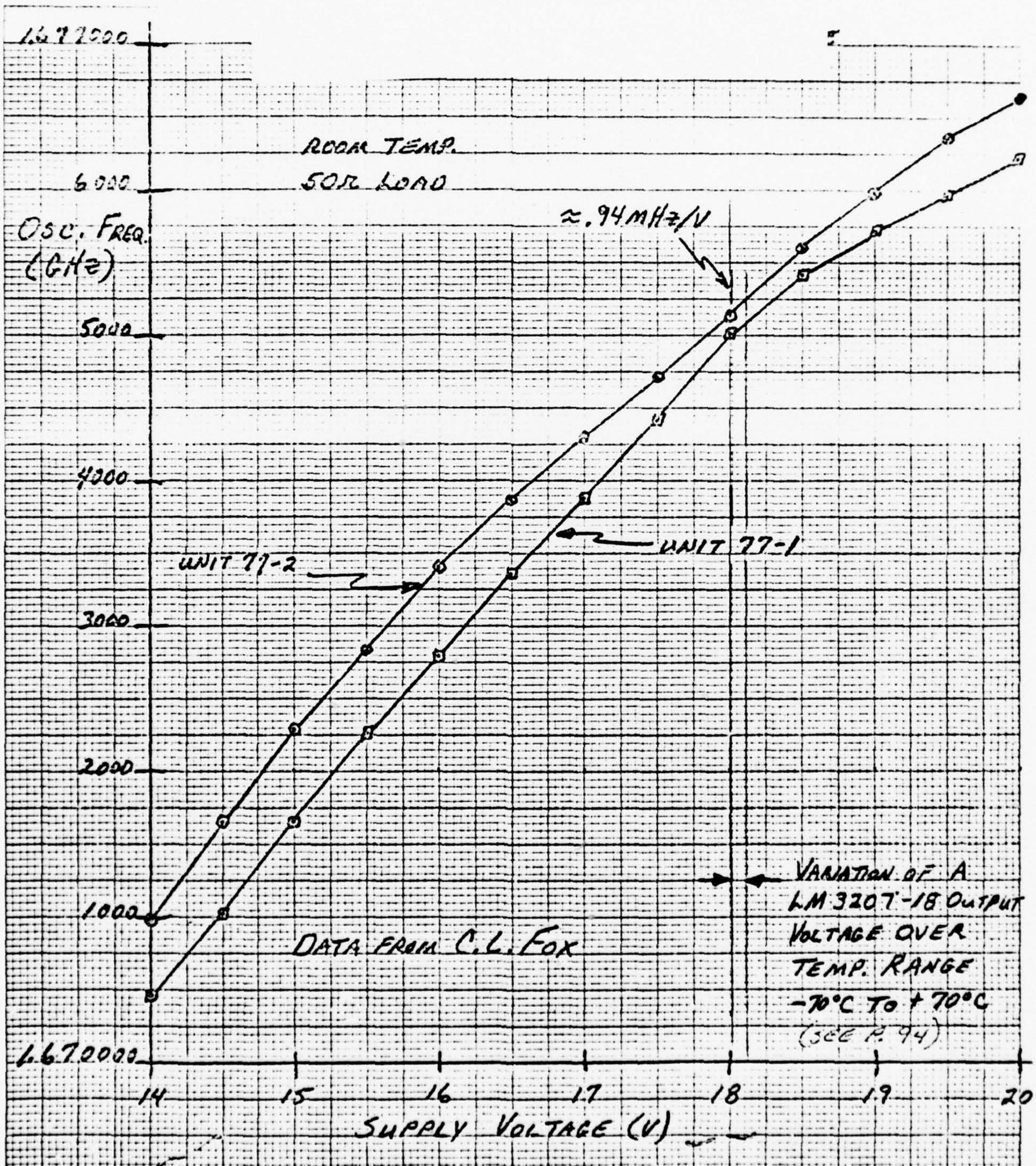


FIGURE 5

RADIOSONDE FREQUENCY STABILITY

EFFECT OF RUTILE VALUE

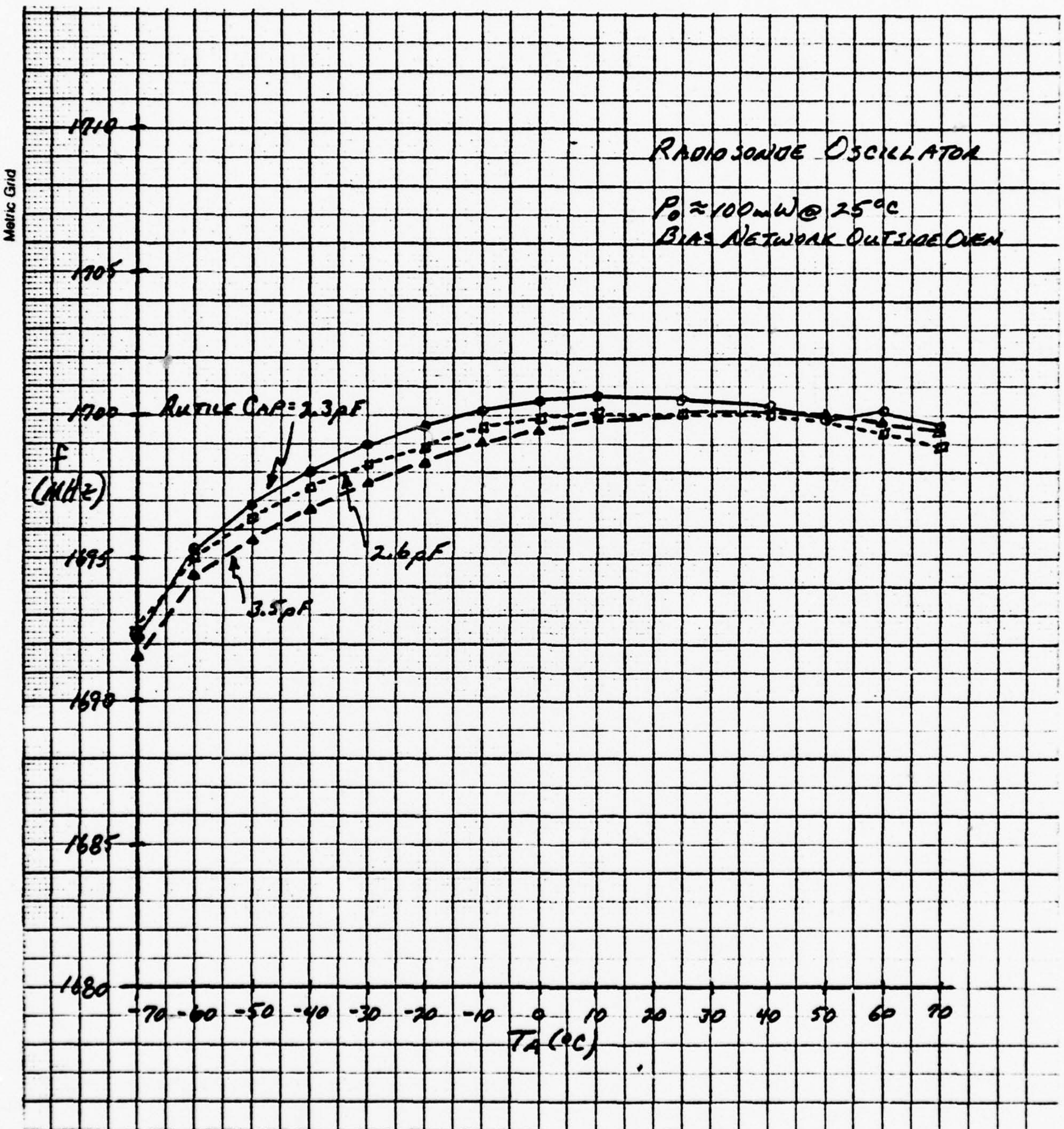


FIGURE 6

RADIOSONDE FREQUENCY STABILITY

EFFECT OF RUTILE LOCATION

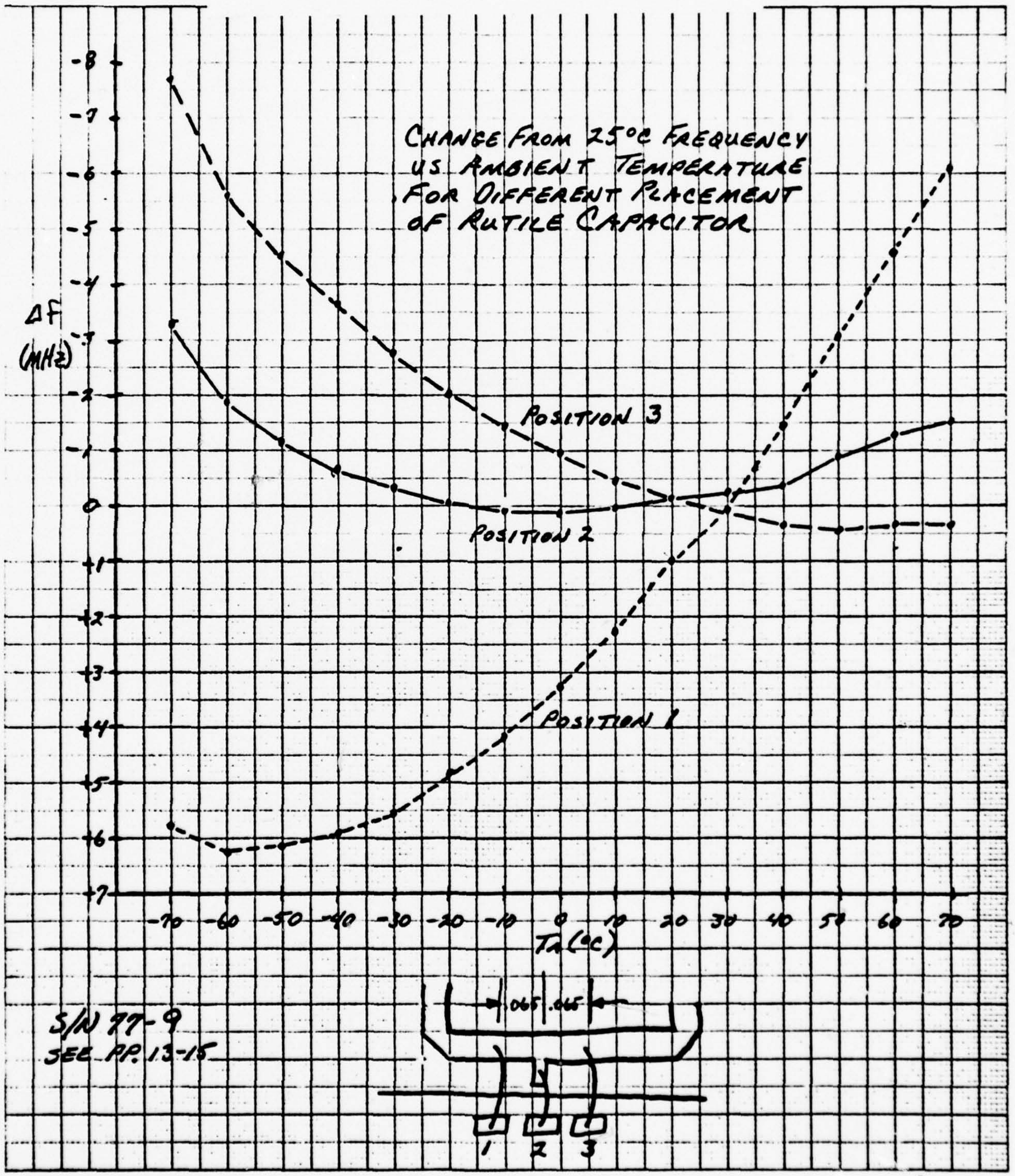


FIGURE 7

Frequency Stability vs. Output Power

The output power is set by a test select resistor as indicated in Figure 1. In production this resistor will be selected for maximum output power without exceeding the current limit (100 ma). Figure 8 is a plot of frequency versus temperature for 105 mw and 135 mw output power. Note that at the higher power level the stability improved 1.26 MHz or 16%. The improvement at the lower temperatures appears to be a result of operating the transistor at a higher current level and therefore at a higher temperature.

Effect of Sealing on the Frequency Stability

Below 0°C water vapor will condense and freeze on the circuit. Frost, with a dielectric constant of about 2, can effect the frequency stability especially if it forms on the rutile capacitor or on the transistor. This idea was explored by testing an oscillator before and after sealing. Sealing was accomplished by drawing a vacuum on the oscillator and then backfilling with nitrogen (N_2). The results, presented in Figure 9, show a significant improvement at the lower temperatures of 2.5 MHz for the sealed unit.

Summary

Two major conclusions can be drawn from these experiments in characterizing the oscillator. The first is that the original design was very close to optimum to begin with, and the second is that there are a number of factors that affect the stability in a minor way but which cummulatively can improve the stability a great deal. By giving proper consideration to these minor factors, the frequency stability requirements can be met.

RADIOSONDE FREQUENCY STABILITY
EFFECT OF OUTPUT POWER LEVEL

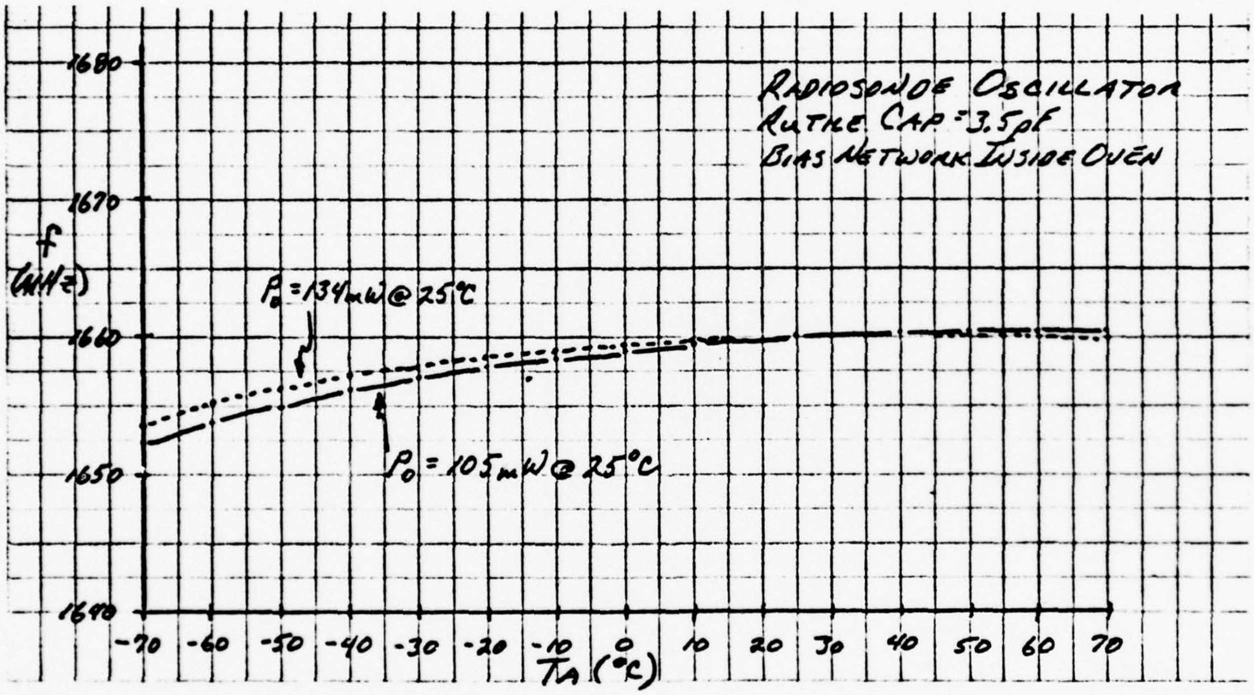


FIGURE 8

RADIOSONDE FREQUENCY STABILITY
EFFECT OF EPOXY SEAL

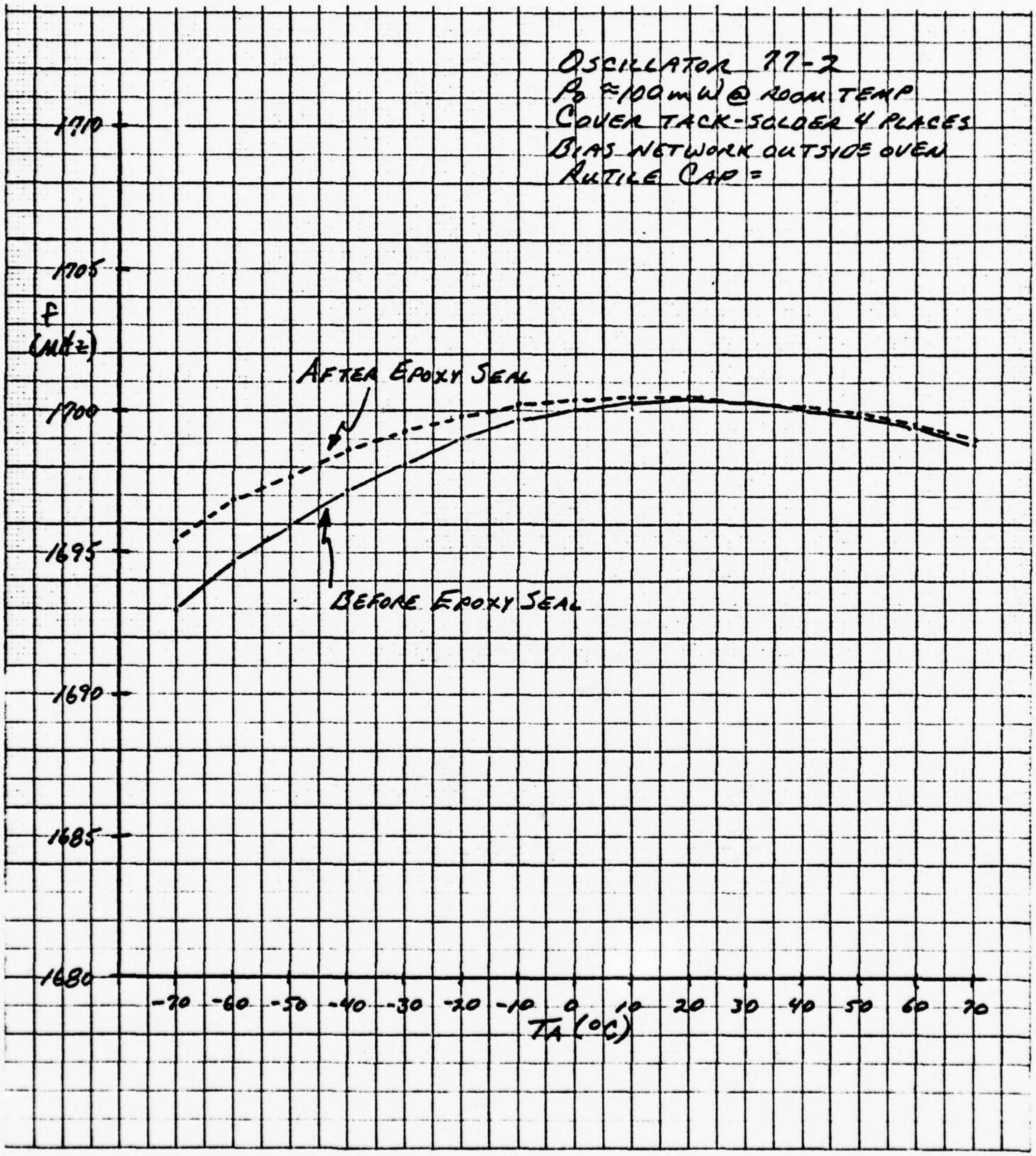


FIGURE 9

2.1.2.2 Modulator Substrate Attachment

The modulator hybrid uses a 25 mil substrate approximately one inch square. For the second set of engineering samples these substrates were attached to the aluminum base plate using a small amount of black non-conductive epoxy, Abelstik 161-3. After hardening, this material is brittle and when the base plate is flexed, either by temperature or by handling, the substrate is placed under stress. This accounted for a number of substrates cracking during the temperature tests. The third set of engineering samples used a different method of substrate attachment. Conformal coating is used routinely to protect substrates from condensation and particle contamination. This coating remains flexible and pliant even at low temperatures and as such has some give to it and can absorb some of the stress from flexing the base plate. This material was used to simultaneously provide a moisture seal over the circuit and to attach the substrate to the base plate. This also eliminated one labor operation and made a cleaner looking assembly. In testing the third set of engineering samples, no modulator substrate problems were encountered.

2.1.2.3 Cone Fabrication

The cone used in the Radiosonde is 20 mils thick formed from a flat sheet of Aluminum by spinning. The flat sheet is drawn over a male form by the application of pressure from a simple round-ended metal tool or a small roller. The spinning process has advantages in low cost, good surface finish and good strength and hardness due to cold working. The formed cone is then silver plate to allow soldering to the baseplate and to the coax cable.

2.1.3 Test Results

Table 2 is a summary of the test results on the third set of engineering samples, serial #21-30. Note that all units easily met the frequency shift with modulation requirement. The spectrum sideband level was checked at the same time and was approximately 40 dBc, 1 MHz from the carrier and 65 dBc, 10 MHz from the carrier (spec is 27 dBc min. 1-10 MHz from the carrier). Two units had pulse widths shorter than 40 μsec. This situation is easily corrected by putting a tighter tolerance on the determining resistor which formerly was specified with a 10% tolerance. A 2% tolerance will fix the problem and can be achieved. An attempt is being made to operate near the narrower end of the pulse-width spec of 60 ± 20 μsec since RCA reported "chirping" problems when wider pulsewidths were used.

As discussed in section 2.1.2.1, the effort to stabilize the oscillator frequency has been successful. Eight of the ten units met the 4 MHz specification with at least a 33% margin. The remaining two units failed by a considerable amount indicating that there was some significant difference in them. Most of the units had adequate output power at -70°C and only two units failed to meet 65 mw minimum. Unit #29 would have had adequate power if the current had initially been set a little higher.

TABLE 2

RADIOSONDE
THIRD ENGINEERING SAMPLES
TEST DATA SUMMARY
WORST CASE OPERATING TEMPERATURE

Unit #	Freq. Shift (KHz)	Pulse Width (μSEC)	Test Freq. (GHz)	Tuning Range (MHz)	ΔFreq./ΔTemp. (MHz)	Power Output (mW)	Current (mA)
21	70	37	1.680	250	2.14	87	97
22*	110	48	1.680	243	2.79	75	96
23*	100	44	1.680	110	5.99	76	96
24	100	44	1.680	276	2.70	56	93.5
25	100	42	1.680	284	1.47	109	98.5
26	50	43	1.701	313	2.72	69	86.5
27	55	44	1.681	143	1.50	104	97.5
28*	50	42	1.680	230	1.91	89	93.5
29	20	38	1.680	230	1.63	64	80.5
30	25	44	1.680	327	8.72	76	95
AVERAGE	68	42.6		240.6	3.16	80.5	93.4
SPECIFICATION	150 Max.	40-80	1.680 Nom.	40 Min.	4 Max.	65 Min.	100 Max.

* The ground plane metallization on these three units was fritted PdAg 9308. Circuit metallization is still fritless PtAg 1130.

2.2 FM SOURCE

2.2.1 Description of the Device

The FM Source is a thick film microwave integrated circuit intended for use as a linear frequency modulated transmitter in applications requiring a rugged, low cost, lightweight device. It consists of a varactor tuned transistor oscillator followed by a transistor power amplifier stage. The oscillator operates at a fixed frequency of 1375 $\pm$ 25 MHz and delivers a minimum of 500 mw into a 50 ohm load. The unit is capable of being frequency modulated at any rate up to 1 MHz by application of a signal on a designated input lead. Total frequency deviation is 50 MHz minimum. The unit is housed in a rugged hermetic structure capable of withstanding severe environmental stress.

The requirements for the FM Source are summarized in Table 4.

2.2.2 Design Considerations

Computer Model

A computer model that can be used to analyze a VCO network has been developed. The inputs to the program are:

1. Equation or equations relating the diode capacitance to the tuning voltage.
2. Equation relating the transistor input reactance to frequency.
3. Tuning network parameters.

The output of the program consists of tables of tuning curves.

The equations relating the diode capacitance to the tuning voltage, for the hyperabrupt diode used in the FM Source, were developed by measuring the diode's C-V characteristic and then approximating it using an exponential curve-fitting program on the HP-25 programmable calculator. To illustrate this, the equations used in this application were:

$$Cd = 12.472 \exp(-.2269 \cdot V_t) + 2.3 \text{ Pf} \quad \text{for } 7 < V_t \leq 20$$

and

$$Cd = 1421.12 \exp(-1.066 \cdot V_t) + 4.0 \text{ Pf} \quad \text{for } 5 \leq V_t < 7$$

The equation relating the transistor reactance to frequency was developed using the program ZFEED (refer to the appendix of the first quarterly report). This program calculates the input impedance, Z_t, of a transistor that uses series feedback based on the measured S parameters of the transistor. As it turns out, the reactive portion of the input impedance when plotted versus frequency over the operating band 1350-1400 MHz is, within a very small error, a straight line. The equation of this line is then input to the VCO program as $\text{IMAG}(Z_t)$

Figure 10 is a schematic of the base tuning network. The constants ℓ_1, ℓ_2, $Z1$, $Z2$ and C_c are input to the program and can be varied to optimize performance over the operating frequency band.

The condition for oscillation that this program analyzes is that

$$\text{IMAG}(Z_t) = \text{IMAG}(Z^*_{net})^1$$

1. *Designates the complex conjugate.

FM SOURCE

BASE TUNING NETWORK

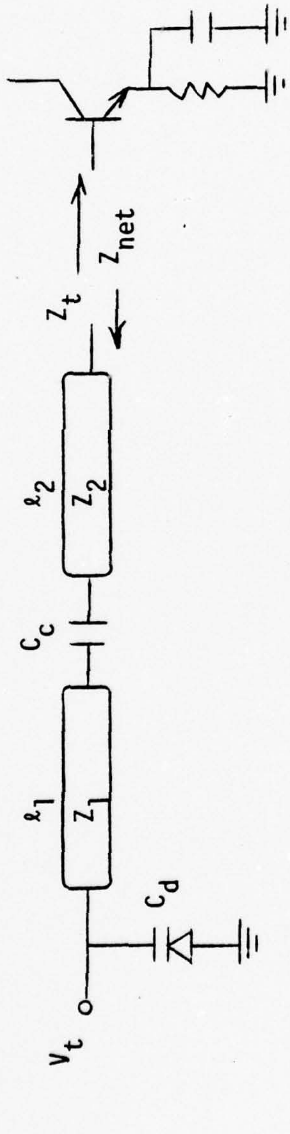


FIGURE 10

Given the network parameters, the equation for $IMAG(Z_t)$, the diode C-V equations and the initial voltage and frequency, the program will (refer to fig. 11) calculate and compare $IMAG(Z_t)$ and $IMAG(Z_{net})$ and increment the frequency until these two quantities are equal but opposite. This yields an ordered pair of numbers; the tuning voltage (V_t) and its corresponding frequency. V_t is then incremented to a higher value and the process is repeated until V_t equals some predetermined cut-off voltage. This entire process is repeated for N sets of network parameters. The curves generated from these tables have the same general shape that characterizes the working units. (See Appendix.)

PA Input Impedance

The input matching network as discussed in the second quarterly report was incorporated into the third set of engineering samples with good results. Figure 12 is a plot of impedance data for this new network for two of the units that were shipped. By adjusting the series capacitor value or the stub length slightly, the impedance curve can be placed anywhere around the center of the Smith chart. The importance of the proper input impedance design was depicted by a load/phase sensitivity test performed on an oscillator. For this test the phase of a 1.67:1 VSWR was varied and data of frequency versus tuning voltage was recorded. Some of this data is shown in Figure 13. For the three oscillators tested the optimum phase ranged from 200° to 225° referenced to the test port connector.

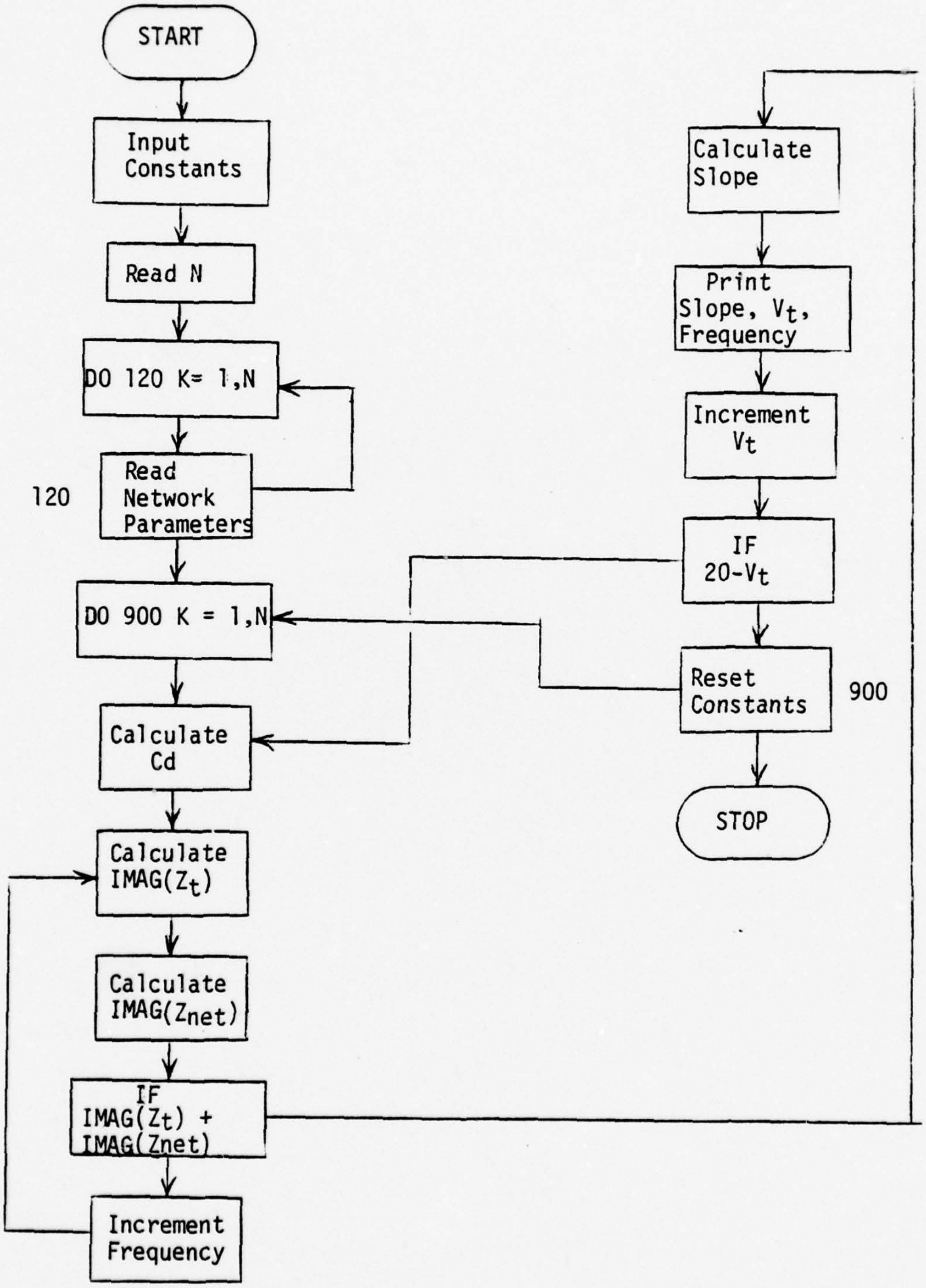

START
Input Constants
Read N
DO 120 K= 1,N
120
Read Network Parameters
DO 900 K = 1,N
Calculate Cd
Calculate IMAG(Z_t)
Calculate IMAG(Z_{net})
IF IMAG(Z_t) + IMAG(Znet)
Increment Frequency
Calculate Slope
Print Slope, V_t, Frequency
Increment V_t
IF 20-V_t
Reset Constants
900
STOP

FIGURE 11

TYPICAL PA INPUT IMPEDANCE

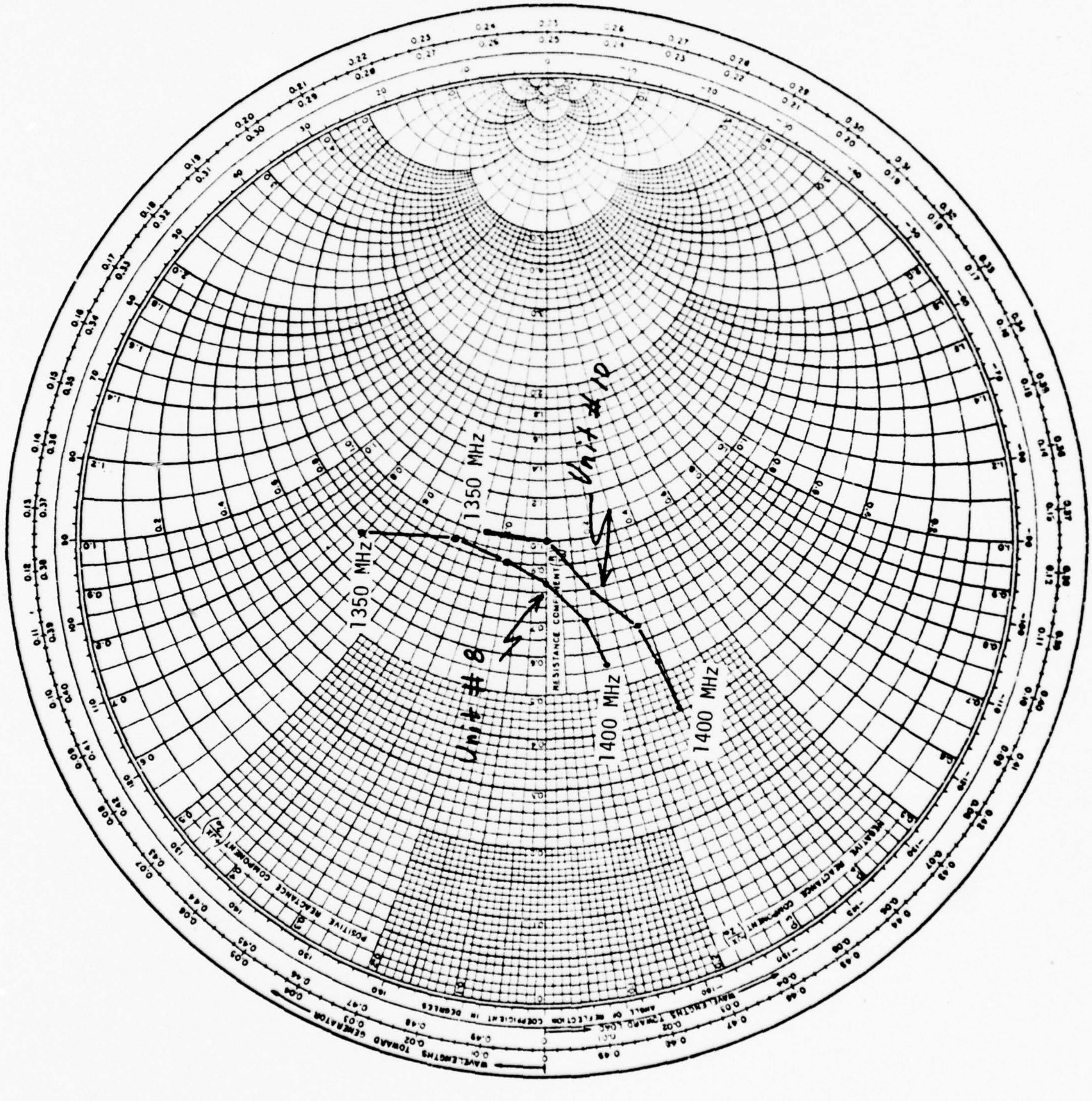


FIGURE 12

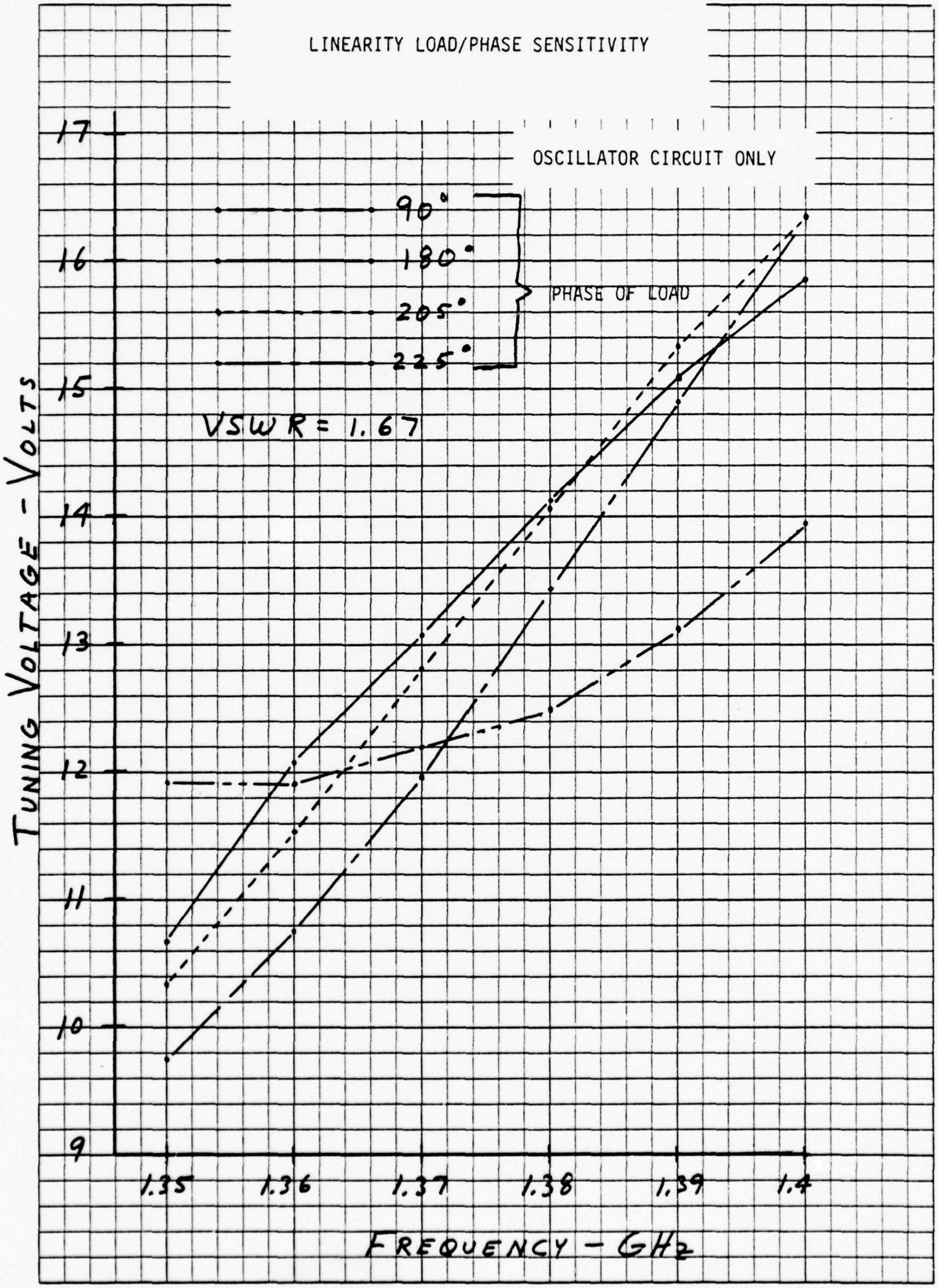

LINEARITY LOAD/PHASE SENSITIVITY
OSCILLATOR CIRCUIT ONLY
90°
180°
205°
225°
PHASE OF LOAD
VSWR = 1.67
TUNING VOLTAGE - VOLTS
17
16
15
14
13
12
11
10
9
1.35
1.36
1.37
1.38
1.39
1.4
FREQUENCY - GHz

FIGURE 13

Artwork and Substrate Revisions

Several major artwork and substrate revisions were made for the third set of engineering samples. The size of the octogon shape substrate was reduced to allow margin in the placement of the substrate on the base plate. Minor changes in the conductor pattern were required to accommodate this size reduction. The major artwork changes were designed to reduce the assembly labor content. All substrate edge grounding straps have been eliminated by rerouting bias lines and adding one extra substrate hole. The feedback resistors were redesigned to a larger more producible size. This increased the feedback capacitance which has increased and stabilized the oscillator output power.

Snapstrate Design

The substrate used in the FM Source is octogon shaped approximately 1.2 x .8 inches. Figure 14 shows the design that is being pursued. The substrate manufacturer will shape the substrate and punch the holes while the substrate is in the green shape. Two octogon substrates will be formed back to back with a snap line impressed. This design will eliminate the labor of laser scoring and breaking the substrate to its final shape and will allow two circuits to be screened and laser trimmed simultaneously, cutting the number of these operations in half. The manufacturer can hold a 1% per linear inch tolerance on the hole and edge location and a 2.5 mil tolerance on the hole size. These tolerances and others associated with the screening operation are being investigated to determine their impact on the circuit layout.

FM SOURCE

SNAPSTRATE DRAWING

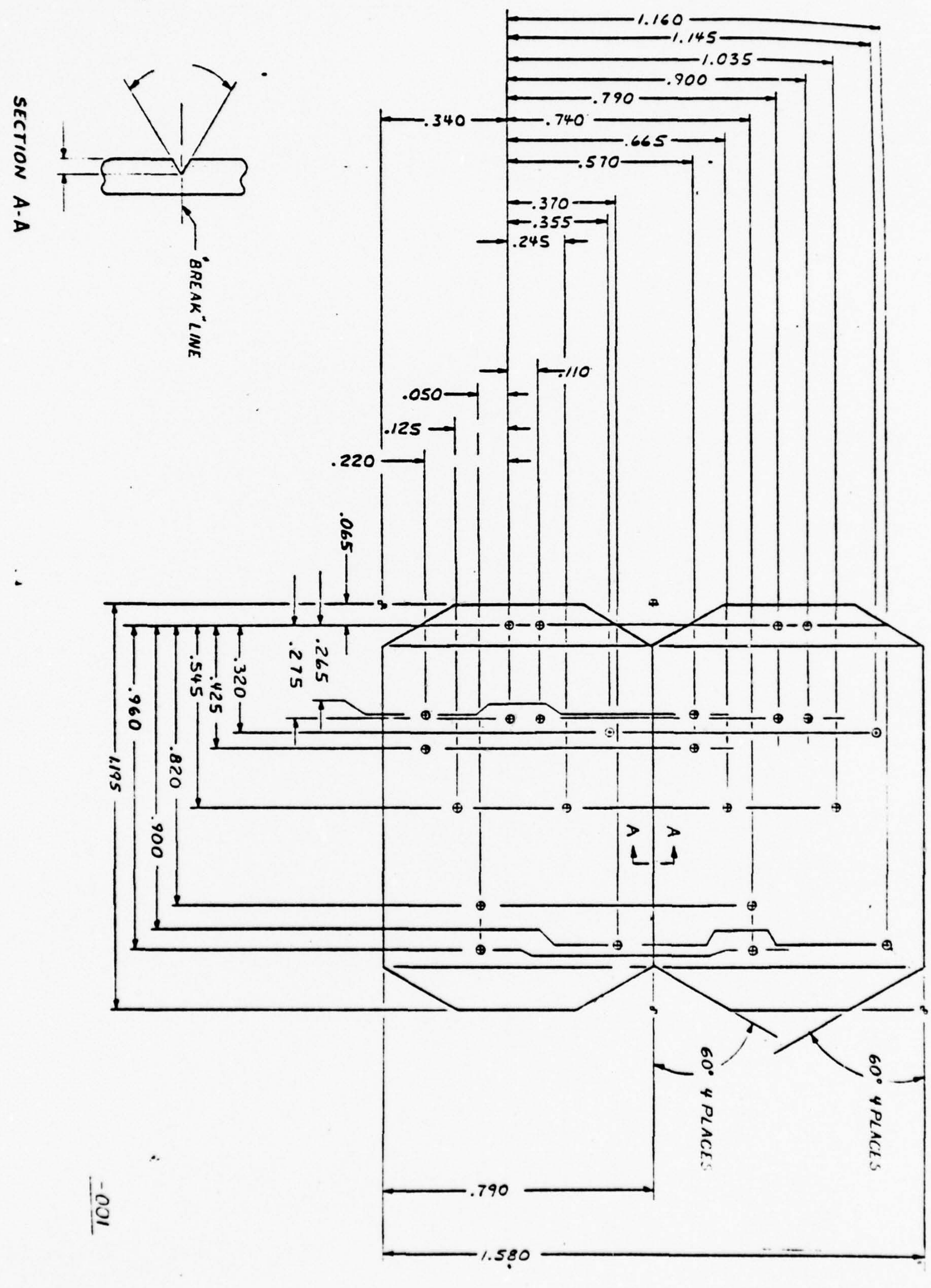


FIGURE 14

Hermetically Sealing the FM Source

The .086 inch coax cable used in the FM Source does not provide a hermetic seal because of the leakage path between the outer wall and the teflon dielectric. To provide a good seal, a small substrate is being designed to fit over the cable as shown in Figure 15. The substrate has backside metallization and is soldered down to the base plate. The center conductor of the coax extends through the substrate and is soldered to the top. This substrate will also be punched while it is in the green state. Snap lines will not be included because the additional tooling cost for this substrate is prohibitive when compared to laser scoring and breaking.

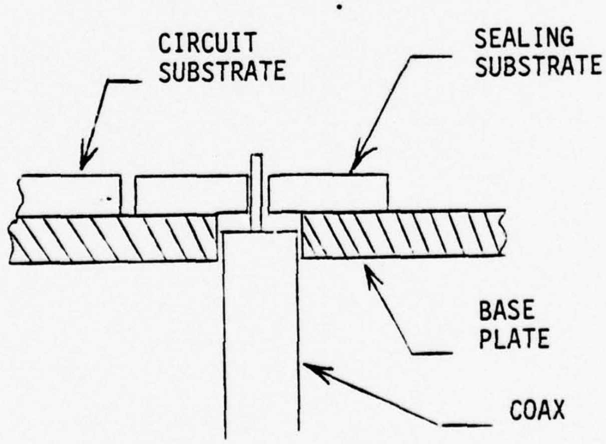


FIGURE 15

The cover to base plate seal is made by welding. The third set of engineering samples were welded and are considered suitable for shock and spin testing. It is anticipated that Harry Diamond Labs will perform shock and spin testing on these units and they have been requested to supply test data by the end of April so that required changes in the fourth set of samples can be made.

2.2.3 PROBLEMS

Frequency Division

As previously reported, the oscillator circuit is frequency dividing which gives the appearance of fm on the carrier. The spectrum line associated with this is at the half frequency, 675 to 700 MHz, approximately 40 dB below the carrier level. Although this is considered by Collins to be a problem, to what extent it is a system problem is not known. What this constitutes is a spurious output on octave from the carrier and 2.5 decades in frequency from the information channel. The impact that this has on the information transfer will have to be determined, and if necessary, a spurious output level spec will have to be included as part of the definitive specification required for the FM Source.

Power Stability vs Temperature

Temperature tests on the third engineering sample revealed that the output power decreases significantly with increasing temperature. Typically, the output power at -40°C was 850 mw while at 70°C, it was 525 mw. This variation in power out is attributed to a combination of effects working against each other. The gain of the PA decreases with increasing temperature (9.4dB at 10°C, 8.54 dB at 70°C). Also, the output power of the oscillator decreases with increasing temperature (87 mw at 10°C, 66 mw at 70°C, Version 0 oscillator). Analyzing the temperature data for the third engineering samples indicates that, in order to meet 500 mw output power over the temperature range, the FM Source must deliver a minimum of 650 mw at room temperature. This by itself is not a major problem since most units met the power out requirement. However, an effort is underway to refine the yield on

this parameter. Unfortunately, associated with this power instability is variation with temperature of the PA input impedance. This variation affects the linearity of the VCO tuning curve. The extent of this problem will require further analysis.

2.2.4 FM SOURCE TESTING

Dynamic Second Order Linearity Test

A test station to test second order linearity has been developed based on the HP3701 and HP3702 Microwave Link Analyzer. The theory of operation is illustrated by the block diagram in Figure 16, where

$$V_{T1} = V_{DC1} + V_{m1}$$

$$V_{T2} = Kf = V_{DC2} + V_{m2}$$

where f = frequency and K = demodulation constant,

$$\text{slope} = \frac{df}{dV_{T1}} = \frac{\frac{1}{K}dV_{T2}}{dV_{T1}} \approx \frac{1}{K}\frac{\Delta V_{T2}}{\Delta V_{T1}} \approx \frac{1}{K}\frac{V_{m2}}{V_{m1}}$$

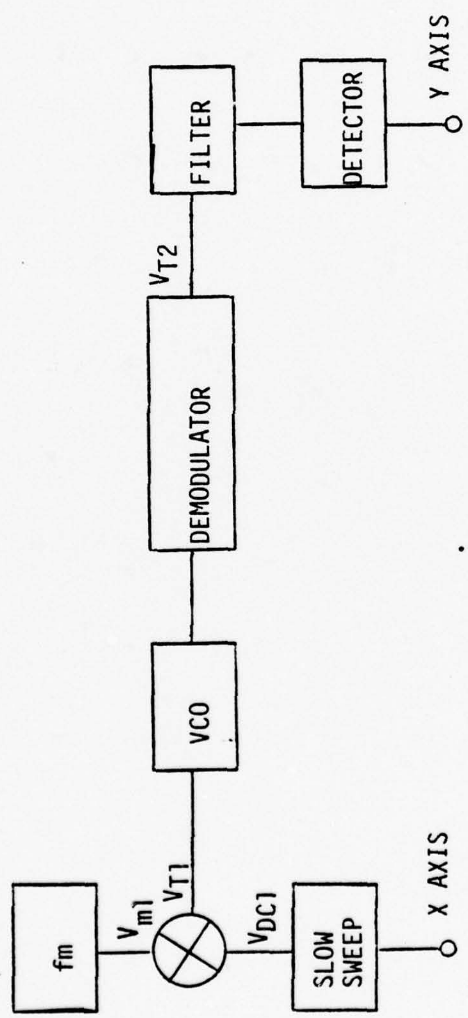
If V_{m1} is a constant, then the instantaneous slope is proportioned to V_{m2}.

A block diagram of the test setup is shown in Figure 17. The VCO frequency is mixed down to the 70 MHz center frequency of the MLA. The setup is capable of sweeping a 50 MHz bandwidth and gives an instantaneous CRT display of the slope; the X axis being frequency and the Y axis being slope in percent deviation per division.

The center frequency voltage of 15 $\pm$ 5 VDC exceeds the sweep voltage capability of the MLA, making it necessary to add a battery or floating supply in series to boost the sweep voltage up to the proper level. This setup was used to test the third engineering samples and will be a valuable aid in future work.

SECOND ORDER LINEARITY TEST

THEORY OF OPERATION



V_{m1} = Modulation Voltage
V_{DC1} = Offset Voltage
V_{T1} = Modulated Tuning Voltage
V_{T2} = Demodulated Voltage

TEST SETUP

SECOND ORDER LINEARITY

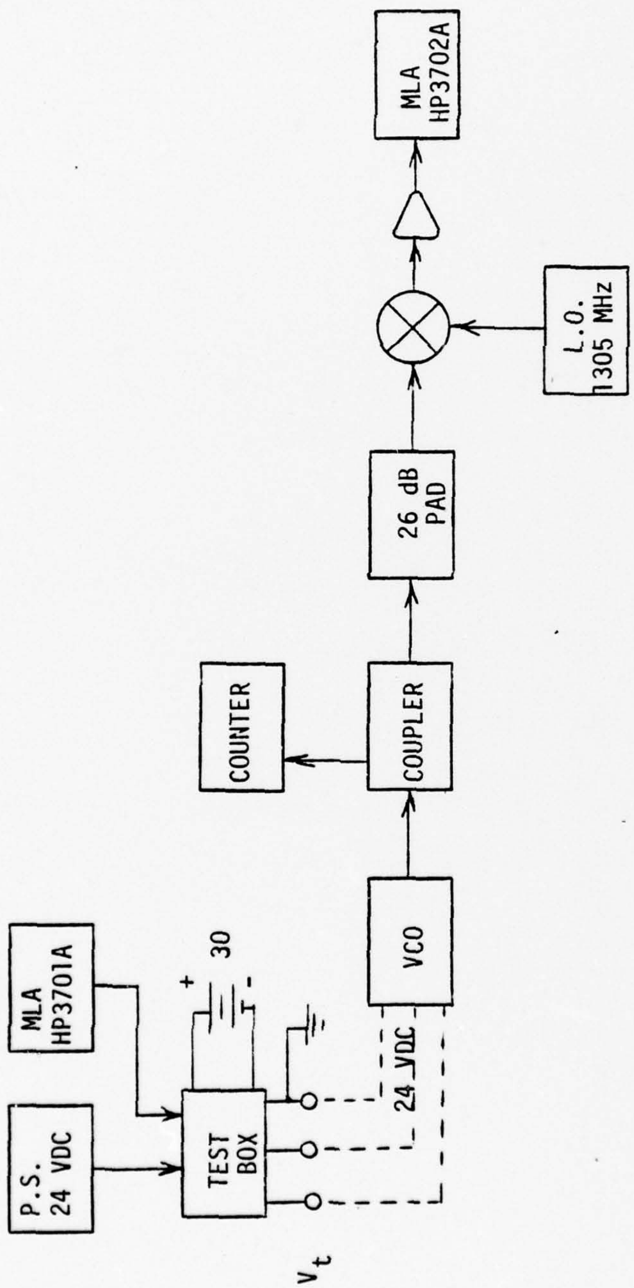


FIGURE 17

First Order Linearity Test

A method to test first order linearity was also investigated to determine if the method met the needs of the FM Source development adequately enough to justify the purchase of the capital equipment. The method is based around the HP9821 programmable calculator, plus peripheral equipment as detailed in Figure 18. Several FM Sources were tested using a general purpose VCO program that has been developed for this calculator. Figure 19 is the plotted test results on one of the units, along with the best least-squares fit straight line plotted upon request. Linearity is calculated and data is printed out on paper tape. Since the second order linearity test yields better dynamic non-linearity information and is less costly to implement, further effort on this first order test, as an engineering tool, has been discontinued.

Test Results

Table 4 gives a summary of the test results on the third set of engineering samples shipped February 28, 1977. First order linearity ranged from .74% to 4.02% with an average of 2.26%. Frequency deviation was measured from a least-squares-fit straight line generated for the measured data using an HP-25C calculator program. This is a 50% improvement over the second set which averaged 5.8%. Second order linearity ranged from ± 7% to ± 22% with an average of 14.4%. The current requirement for unit #22 was high because the resistors were the as-fired values, and the oscillator is drawing 10-15 ma more than normal. All units received -40°C to +70°C temperature testing, and the data in Table 5 is worst case results.

FM SOURCE

FIRST ORDER LINEARITY

TEST SETUP

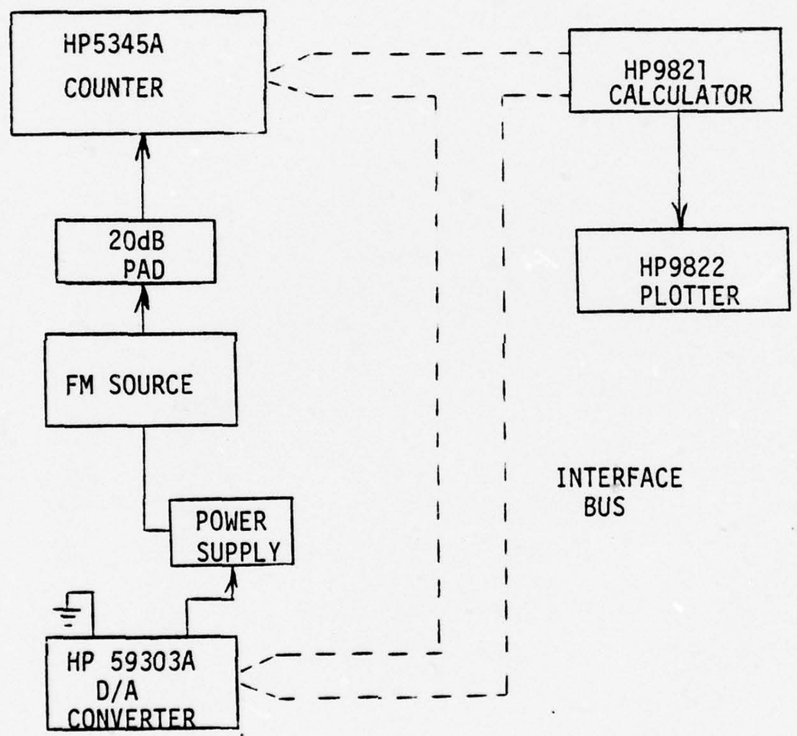


FIGURE 18

FM SOURCE TUNING CURVE

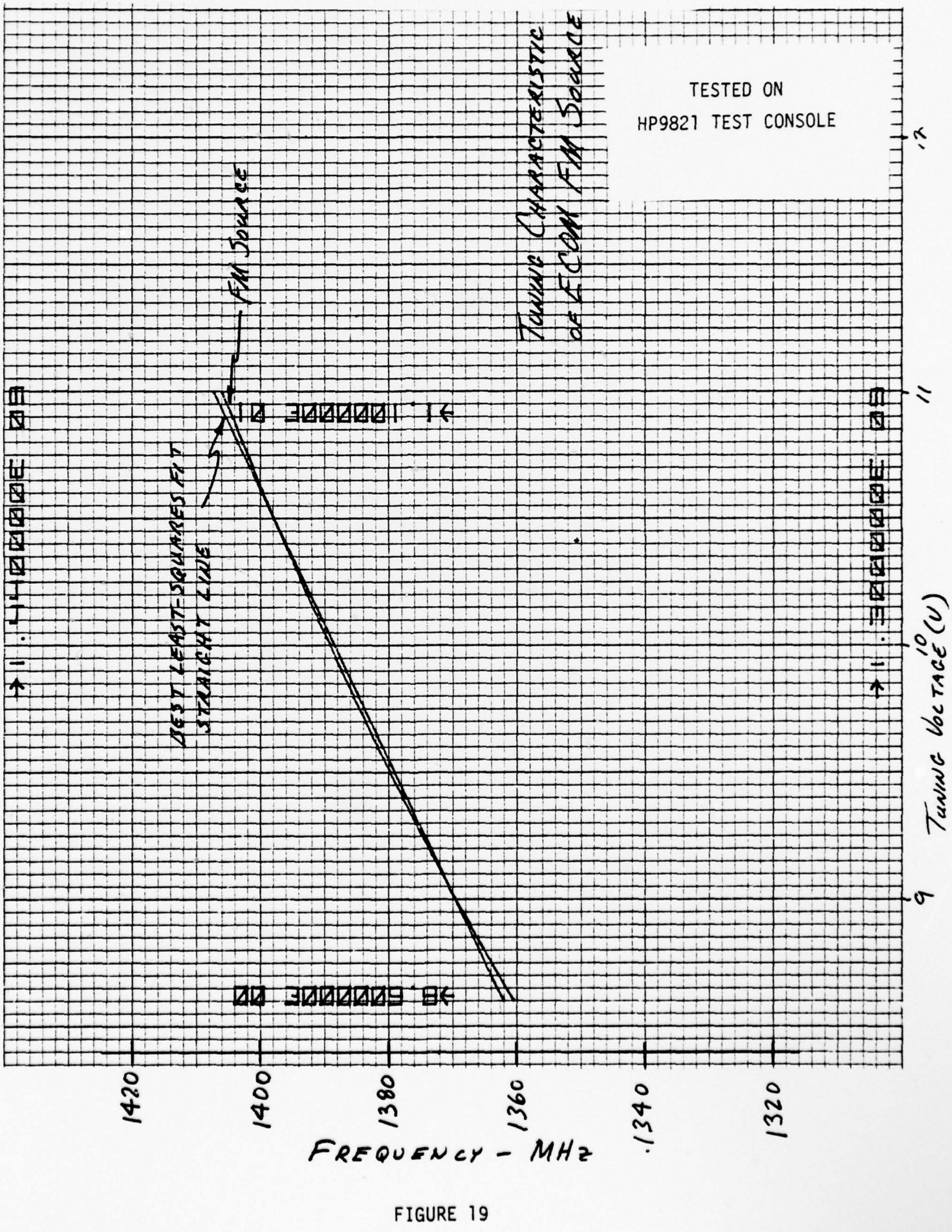


FIGURE 19

TABLE 4

FM SOURCE
THIRD ENGINEERING SAMPLES
TEST DATA SUMMARY
WORST CASE OPERATING TEMPERATURE

S/N	POWER OUTPUT (mW)	CURRENT (mA)	1375 MHz VOLTAGE @25°C (V)	FIRST ORDER LINEARITY @25°C (%)	SECOND ORDER LINEARITY @25°C (%)
21*	505	159	19.45	3.20	± 22
22*	520	185	22.72	3.56	± 20
23*	450	150	20.29	4.02	± 22
24	585	169	19.82	1.57	± 10
25	445	165	17.86	3.63	± 13
26	535	177	20.71	.95	± 8
27	580	170	18.49	1.80	± 20
28	575	171	18.38	.74	± 7
29	555	183	21.86	1.59	± 10
30	490	173	16.95	1.50	± 12
AVERAGE	524	170.2	19.65	2.26	± 14.4
SPECIFICATION	500 Min.	175 Max.	15±5 VDC		± 2%

* FRITLESS Au METALLIZATION

2.3 MATERIALS EVALUATION

Q Measurements

As a continuation of the Q measurements carried out in the second quarter, several substrates were coated with either conformal coating or solder, and the degradation in Q from the uncoated value was determined. Fritless gold E/O 6990 and fritless PtAg E/O 1130 were selected since they are candidate pastes for the FM Source and the Radiosonde. For the conformal coating measurement, the Q was first determined on the uncoated substrate; then after coating, the measurement was retaken. In the case of the solder coating measurement, the precoat values were generated several months earlier. 75 ohm data could not be taken because solder dipping the substrates tended to leach the narrow resonator line. Data is summarized in Figures 20-22.

Data of Q on substrates with a 10μ inch surface finish was taken for the same two conductor materials. The data for PtAg coincided directly with the 34μ inch data presented in the second quarterly report. Data for the gold fell below that of the 34μ inch surface finish data by about 10%.

Screened-Thru-Holes

The ability to screen-thru-holes is a distinct advantage of thick film technology. The present design of the FM Source uses 12 holes to complete both DC and RF ground connections. Thus in terms of RF, the quality of the ground is important. Experiment 17 of the materials evaluation program was designed to determine the optimum hole size for a given substrate thickness and what kind of yield would be expected.

After printing and firing, the holes were checked for DC conductivity and for cosmetic appearance. Table 5 is a summary of the results. For a 25 mil substrate, a .025 to .040 diameter hole is optimum. For a 40 mil substrate, a .025 to .030 hole diameter is appropriate. The 60 mil substrate is too thick to consistently pull a sufficient quantity of paste through the hole to complete the connection.

Bond Strength Tests

Experiments were run to determine the thick film materials best suited for applications requiring extensive wire bonding or where the strength of the bond is important (as in the FM Source). The materials evaluated were:

1.	Au	EO/6990	Fritless
2.	Au	Dupont 9797	Fritted
3.	PtAu	Dupont 9885	Fritted
4.	PtAg	Dupont 9770	Fritted
5.	PtAg	E/O 1130	Fritless
6.	PdAg	Dupont 9308	Fritted
7.	Cu	Cermalloy 7029	Fritted

The bonds were subjected to 48 hours at 150°C before testing. In all cases, the wire itself broke before the bond pulled apart. The average force required for breaking the bond wire was between 6 and 8 grams.

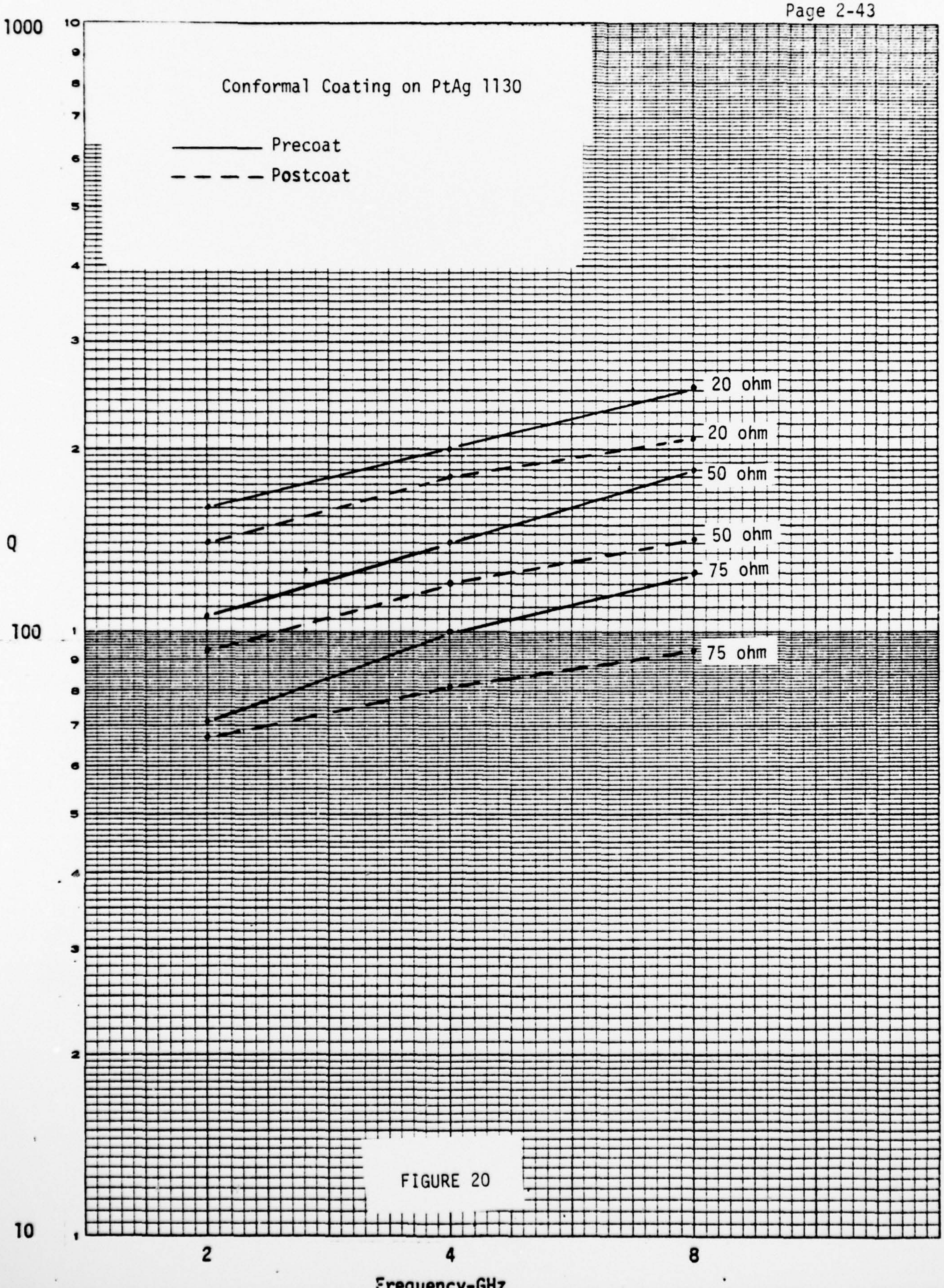

Conformal Coating on PtAg 1130
Precoat
Postcoat
20 ohm
20 ohm
50 ohm
50 ohm
75 ohm
75 ohm
1000
100
10
Q
2
4
8
Frequency-GHz

FIGURE 20

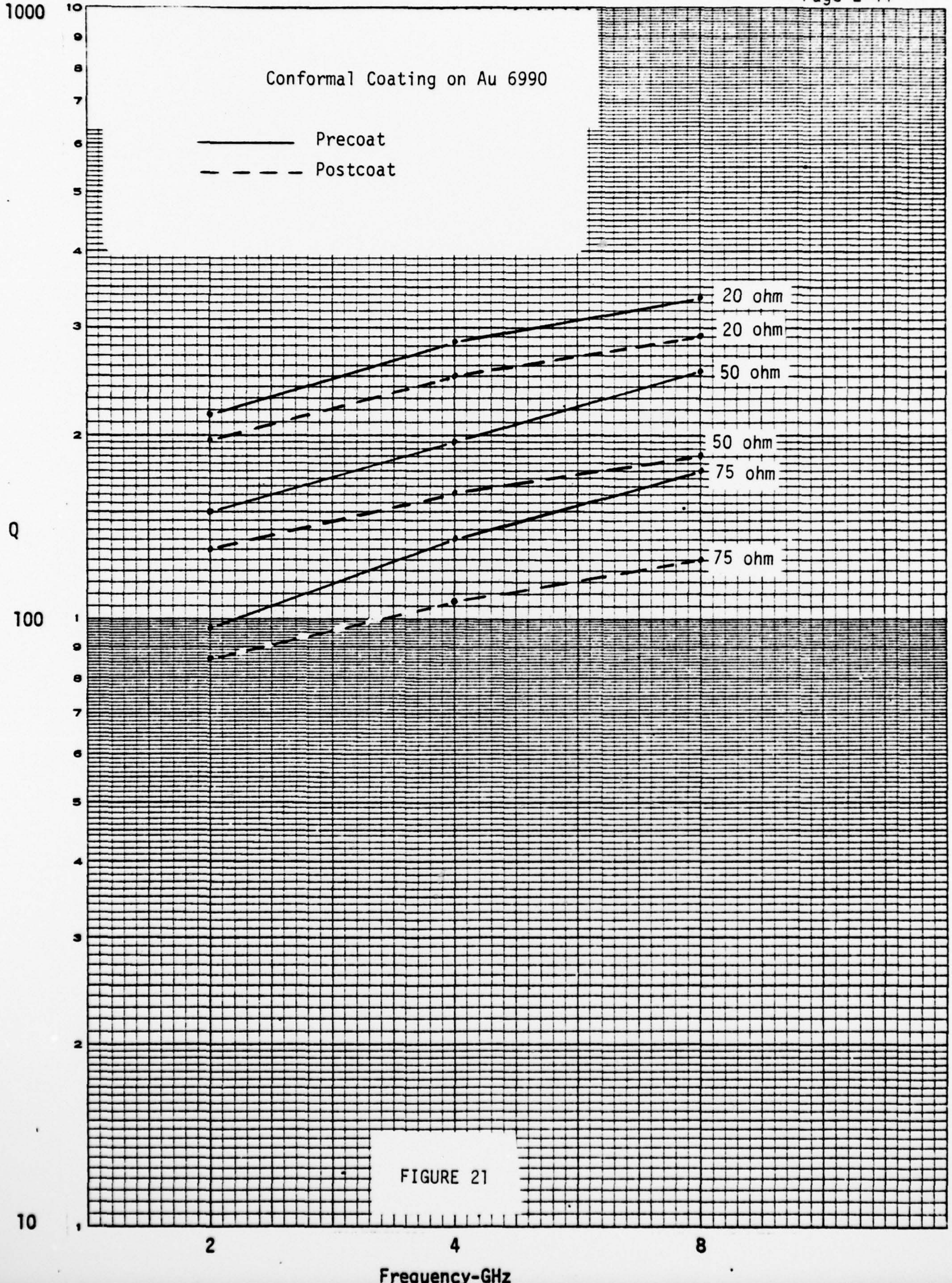

Conformal Coating on Au 6990
Precoat
Postcoat
20 ohm
20 ohm
50 ohm
50 ohm
75 ohm
75 ohm
1000
100
10
Q
2
4
8
Frequency-GHz

FIGURE 21

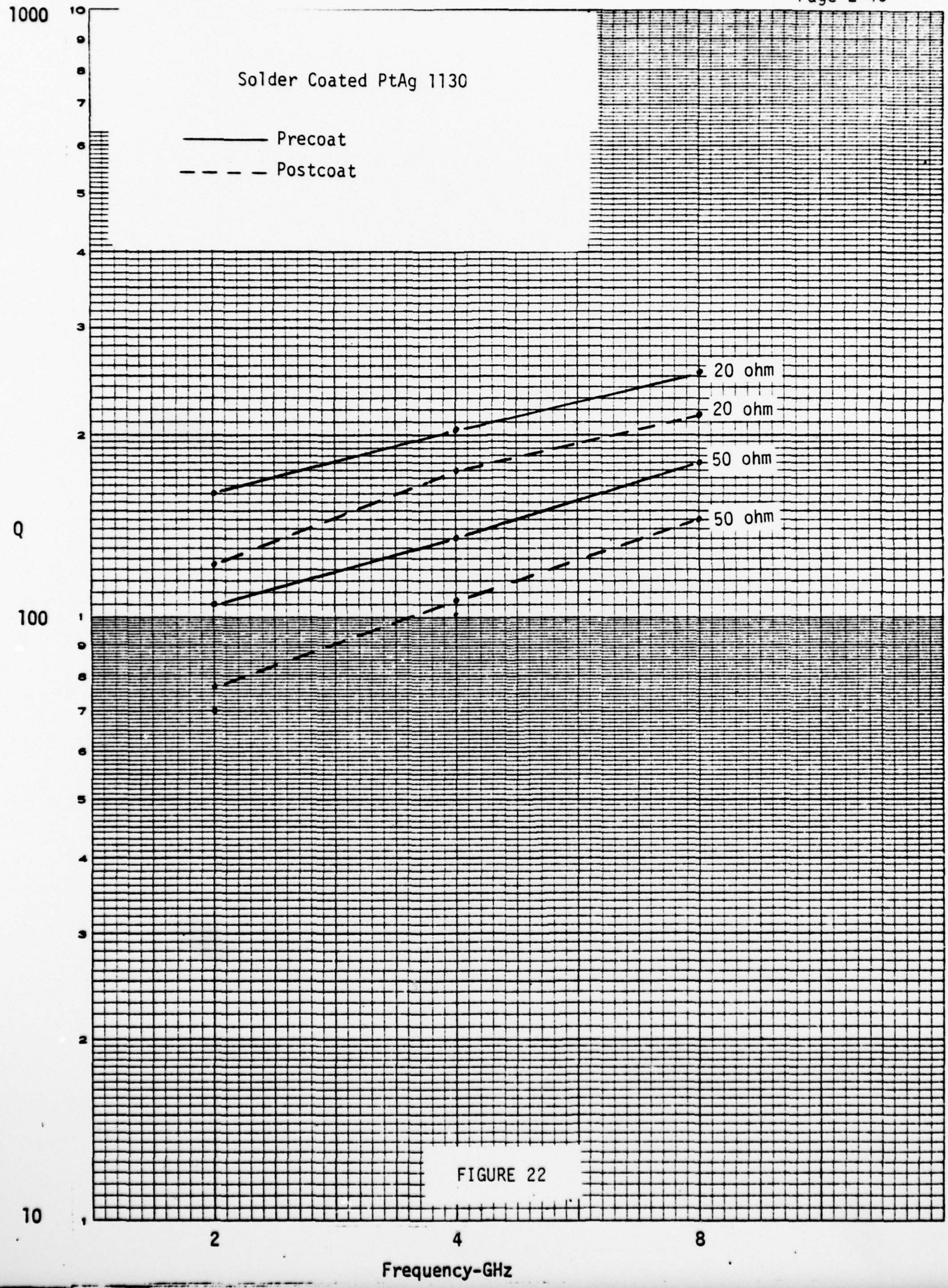

Solder Coated PtAg 1130
Precoat
Postcoat
20 ohm
20 ohm
50 ohm
50 ohm
1000
100
10
Q
2
4
8
Frequency-GHz

FIGURE 22

TABLE 5

YIELD RESULTS OF

THE SCREENED THRU HOLE EXPERIMENT

HOLE DIAMETER	SUBSTRATE THICKNESS .025	.040	.060
.020	197/200 YIELD=98.5%	174/176 98.9%	8/160 5%
.025	200/200 100%	176/176 100%	44/160 27.5%
.030	200/200 100%	176/176 100%	80/160 50%
.040	200/200 100%	167/176 94.9%	57/160 35.6%

MATERIAL - DUPONT 9308

MESH SIZE - 200

2.4 PROCESS EQUIPMENT AND TOOLING

The processes and assembly techniques developed during the second quarter of this program were used in the build of the third set of engineering samples and, at this time, are considered acceptable fabrication methods. Minor modifications were made to eliminate labor operations. For the Radiosonde, the two-step operation of epoxying the modulator substrate down to the base plate and then conformal coating it has been replaced by a one-step operation where the conformal coating is used to both seal the substrate and attach it to the base plate. In the fabrication of the FM Source, artwork changes and the addition of one substrate hole has eliminated the assembly operation where ground straps are welded around the edge of the substrate. This also allows the substrate to be flat on the base plate which, besides being more rugged, also improves the RF ground connection.

At this time, an effort is underway to define and design the tooling required for the assembly and test of the Confirmatory Samples and the pilot production units and to specify and procure any test equipment that will be needed for these builds.

Welding

A method to seal the lids on the FM Source was evaluated on the third set of engineering samples. A tungsten inert gas (TIG) welder was manually operated to seal the units. To prevent the silver plating from bubbling and oxidizing, because of excess heat during the welding operation, the lid and base plate have to be either selectively plated or the plating has to be selectively removed from the weld area. This sealing operation, which manually is too slow to handle a high production rate, will, for production, be performed in an automatic weld system capable of welding one unit in about ten seconds.

SECTION 3

CONCLUSIONS

3.1 Radiosonde Modulator/Transmitter

The thrust of this past quarter effort was directed toward solving the frequency stability problem on the oscillator and the substrate cracking problem on the modulator board. Both have been successfully resolved. Test results indicate, however, that further effort is required to increase the yields on the frequency stability and minimum output power to levels acceptable for high volume production. Production planning efforts have been minimal pending a final decision on the future of the Radiosonde development at Collins Radio.

3.2 FM Source

Significant progress has been made on development of the FM Source this past quarter. A second order linearity test has been developed, and autotest and production planning is underway. Electrically, the third set of engineering samples are more repeatable and linear than previous engineering samples. The PA input match has been improved, thereby increasing the isolation between the stages. The circuit layout and mechanical design has been refined to the point where assembly labor is minimal and compatable with reflow solder techniques. Effort is required to optimize the present design, to prepare a definitive specification on the FM Source, and to complete plans for the upcoming build of Confirmatory Samples.

SECTION 4

PROGRAM FOR NEXT INTERVAL

4.1 Radiosonde

The following objectives are planned for the next reporting period:

1. Fabricate and test the fourth set of engineering samples.
2. Finalize the Radiosonde Modulator/Transmitter drawing package.
3. Resolve the future of the Radiosonde effort at Collins and act accordingly.

4.2 FM Source

The following objectives are planned for the next reporting period:

1. Complete Autotest program and debug using fourth engineering samples.
2. Fabricate and test the fourth set of engineering samples.
3. Complete production planning for the build of the confirmatory samples.
4. Complete acceptance test plans for the confirmatory samples.
5. Resolve the electrical problems associated with the FM Source.

4.3 Materials Evaluation

The following objectives are planned for the next reporting period:

1. Complete life testing of screened-thru-holes.
2. Generate final report on materials evaluation effort.

SECTION 5

5.0 IDENTIFICATION OF PROJECT PERSONNEL

The personnel directly related to the ECOM project are listed in Table 6 along with the number of hours in which they have been involved during this quarter. Resumes of personnel new to the project are included.

Table 6

Identification of Project Personnel

Personnel	Titles	Hours
R. E. Shipley	Program Manager	
J. K. McCoy	Project Engineer	360
K. W. Hoover	Design Engineer (Elect.)	300
L. G. Ward	Design Engineer (Mech.)	35
H. D. Jenkins	Mechanical Engineer/Group Head	9.5
R. Cadenhead	Senior Process Engineer	56
C. L. Fox	Senior Technician	400
V. Miller	Assembly Technician	160
D. Warner	Thick Film Technician	160

K. W. HOOVER

POSITION: Project Engineer, RF Products Department
Hybrid Microelectronics Division

EDUCATION: BSEE, Virginia Polytechnic Institute, Blacksburg, Va. 1972; Graduate Work in Electrical Engineering, Southern Methodist University, Dallas, Tex. 1972-3; Currently pursuing an MMAS Degree at University of Texas, Dallas, Tex.

Mr. Hoover joined Collins in 1973. Since that time, his design activities have included computer-optimized broadband UHF amplifiers for airborne military communications, microstrip S-band power amplifiers for commercial microwave communications, low power linear amplifiers in the 10-1000 MHz band, and passive components such as couplers and attenuators for microwave integrated circuits. Specific project engineering responsibilities have included the development of a 15 Watt S-band integrated PA module for the Collins MS228 microwave radio and the development of a cost-reduced 15 Watt UHF linear amp for airborne applications. Mr. Hoover has headed several programs aimed at improving the manufacturability of RF hybrids. As project engineer, he was instrumental in moving RF Products' UHF hybrid PA's for the Collins ARC 159 radio from initial production to a high-yield, cost-effective product line. Mr. Hoover also participated in the design of an integrated L-band transceiver for the Advanced Research Projects Agency and contributed to a study on future trends in integrated MIC design for that agency.

Prior to joining Collins, Mr. Hoover worked at Texas Instruments, Inc. of Dallas. At TI, his work was in two areas: (1) hybrid MIC amplifiers and local oscillators, and (2) voltage controlled Gunn local oscillators for Airborne Military Radar.

SECTION 7

APPENDIX

VCO PROGRAM

```
      DIMENSION CC(20),L1(20),Z1(20),L2(20),Z2(20)
      REAL L1,L2
      COMPLEX X,XCD,XCC,J,X1,X2,X3
      F1=1300.E6
      F0=1.3E9
      V=1.18E10
      VTUNE=5.
      K=0
      JDUMMY=0
      READ(8,100) N
  100 FORMAT(I2)
      DO 120 K=1,N
      READ(8,110) CC(K),L1(K),Z1(K),L2(K),Z2(K)
  110 FORMAT(T1,F5.1,T10,F5.3,T20,F4.1,T30,F5.3,T40,F4.1)
  120 CONTINUE
      DO 900 K=1,N
      F=F1
      WRITE(7,110)  CC(K),L1(K),Z1(K),L2(K),Z2(K)
  125 CONTINUE
      IF(7.-VTUNE) 200,300,300
  130 CONTINUE
      GO TO 350
  200 CD=(12.472*EXP(-.2269*VTUNE)+2.3)*1.E-12
      GO TO 130
  300 CD=(1421.12*EXP(-1.066*VTUNE)+4.)*1.E-12
      GO TO 130
  350 CONTINUE
      XTRAN=F*7.86E-8-119.727
      W=6.2832*F
      WINV=-1./W
      X=CMPLX(0.,WINV)
      XCD=X/CD
      A1=L1(K)*W/V
      A2=L2(K)*W/V
      J=CMPLX(0.,1.)
      ZA=Z1(K)
      ZB=Z2(K)
      X1=ZA*((XCD*COS(A1)+J*ZA*SIN(A1))/(ZA*COS(A1)+J*XCD*SIN(A1)))
      XCC=(X/CC(K))*1.E12
      X2=X1+XCC
      X3=ZB*((X2*COS(A2)+J*ZB*SIN(A2))/(ZB*COS(A2)+J*X2*SIN(A2)))
      XNET=AIMAG(X3)
      DELTA=XTRAN+XNET
      IF(DELTA) 600,500,500
  500 SLOPE=(F-F1)/.1
      WRITE(7,550) VTUNE,F,SLOPE
  550 FORMAT(T5,F5.2,T20,4PE12.3,T35,2PE9.3)
      F1=F
      VTUNE=VTUNE+.1
      IF(20-VTUNE) 700,125,125
  700 VTUNE=5.
      F1=F0
      JDUMMY=0
  900 CONTINUE
      GO TO 999
  600 F=F+.1E6
      JDUMMY=JDUMMY+1
      IF(5000-JDUMMY) 999,999,130
  999 STOP
      END
```

VCO PROGRAM

SAMPLE OUTPUT

@XQT

8.0	.428	50.0	.428	50.0
C_c	l_1	Z_1	l_2	Z_2

TUNING VOLTAGE	FREQUENCY	SLOPE MHz/volt
5.00	1417.900+06	11.790+06
5.10	1423.600+06	57.000+06
5.20	1429.400+06	58.000+06
5.30	1435.100+06	57.000+06
5.40	1440.800+06	57.000+06
5.50	1446.500+06	57.000+06
5.60	1452.000+06	55.000+06
5.70	1457.400+06	54.000+06
5.80	1462.600+06	52.000+06
5.90	1467.700+06	51.000+06
6.00	1472.600+06	49.000+06
6.10	1477.200+06	46.000+06
6.20	1481.700+06	45.000+06
6.30	1485.900+06	42.000+06
6.40	1489.900+06	40.000+06
6.50	1493.600+06	37.000+06
6.60	1497.100+06	35.000+06
6.70	1500.400+06	33.000+06
6.80	1503.400+06	30.000+06
6.90	1506.300+06	29.000+06
7.00	1508.900+06	26.000+06
7.10	1509.700+06	80.000+05
7.20	1511.300+06	16.000+06
7.30	1512.900+06	16.000+06
7.40	1514.600+06	17.000+06
7.50	1516.200+06	16.000+06
7.60	1517.800+06	16.000+06
7.70	1519.400+06	16.000+06
7.80	1521.000+06	16.000+06
7.90	1522.600+06	16.000+06
8.00	1524.100+06	15.000+06
8.10	1525.700+06	16.000+06
8.20	1527.200+06	15.000+06
8.30	1528.700+06	15.000+06
8.40	1530.300+06	16.000+06
8.50	1531.800+06	15.000+06
8.60	1533.300+06	15.000+06
8.70	1534.700+06	14.000+06
8.80	1536.200+06	15.000+06
8.90	1537.600+06	14.000+06
9.00	1539.100+06	15.000+06
9.10	1540.500+06	14.000+06
9.20	1541.900+06	14.000+06
9.30	1543.300+06	14.000+06